NISTIR 6890

Fire Resistance Determination and Performance Prediction Research Needs Workshop: Proceedings

William Grosshandler
Editor

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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Technology Administration
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O. Fire Resistance and Performance Prediction: Structural Analysis Issues and Research Needs

James Ricles, Department of Civil and Environmental Engineering
Lehigh University, Bethlehem PA

(see file App III O.pdf)

Behavior of Structures in Extreme Events

James Ricles
Department of Civil and Environmental Engineering
Lehigh University, Bethlehem, PA

NIST Workshop on
Fire Resistance Determination and Performance Prediction

February 19-20, 2002

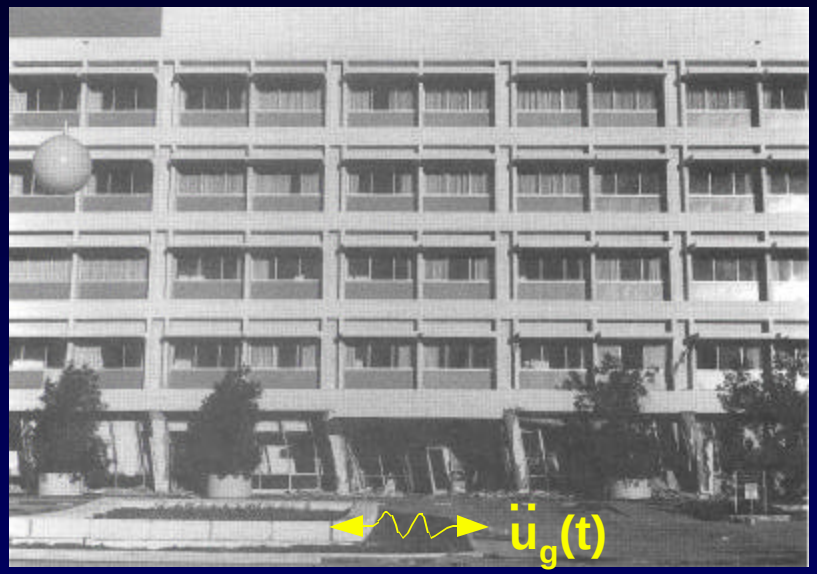
Presentation

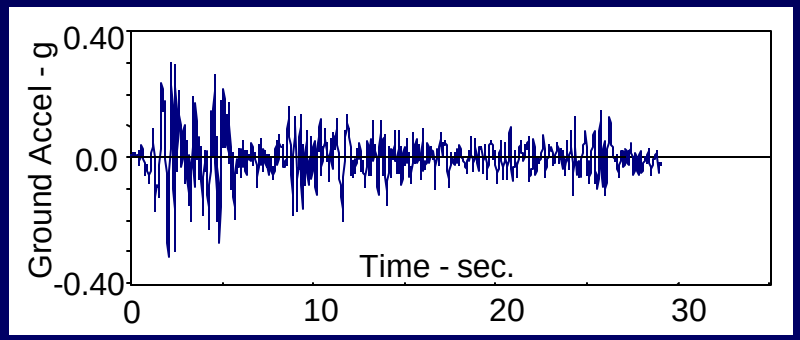
- Response of Structures to Severe Earthquakes
- Elevated Temperature Effects on Structural Steel Systems
- Research Needs for Fire Resistance Determination and Performance Prediction

Response of Structures to Severe Earthquakes

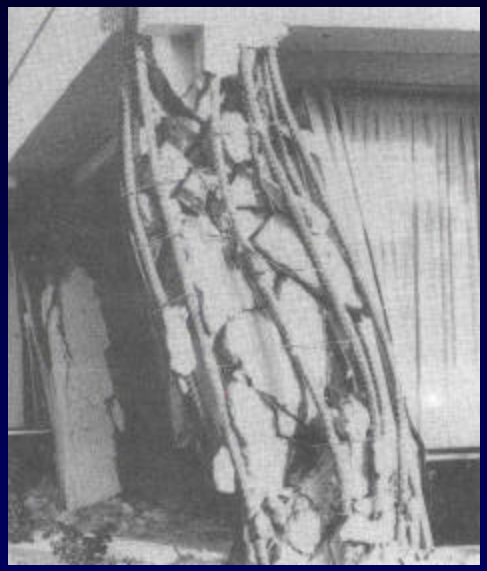
Damage to Olive View Hospital from 1971 San Fernando EQ

Soft-story Mechanism





Column Failure



Source: Chopra, 2001

Structural Response Prediction to Earthquakes

Analysis

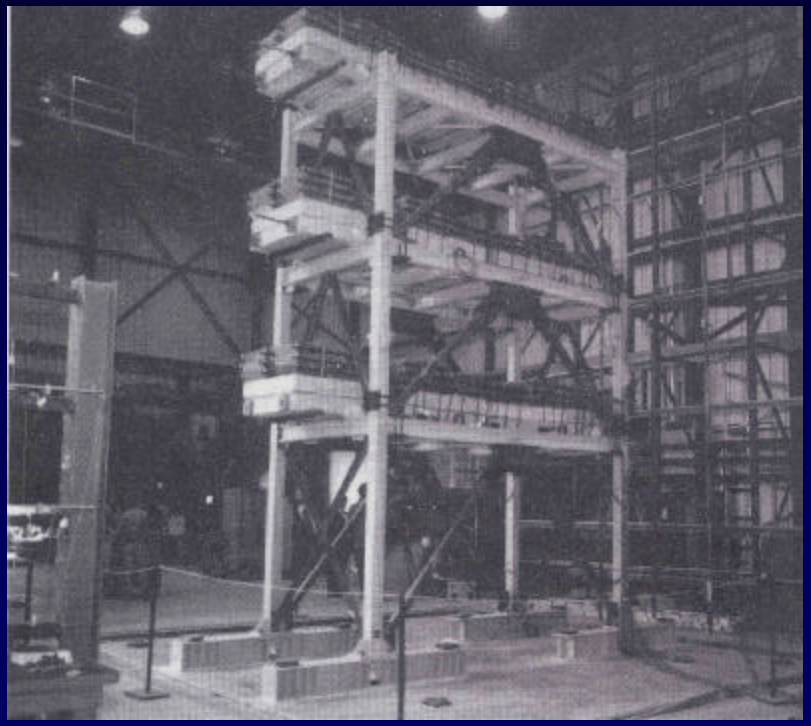
- Material modeling (non-linearities)
  - Cyclic plasticity
  - Cyclic degradation of material stiffness and strength
  - Fracture
- Geometric non-linearities
  - Local buckling
  - Global instabilities (P-Δ effects)

Experimental testing

  - Database on real performance
  - Proof of concept
  - Calibration of analytical models

Earthquake Structural Performance Evaluation
Experimental Testing

Shake Table Testing

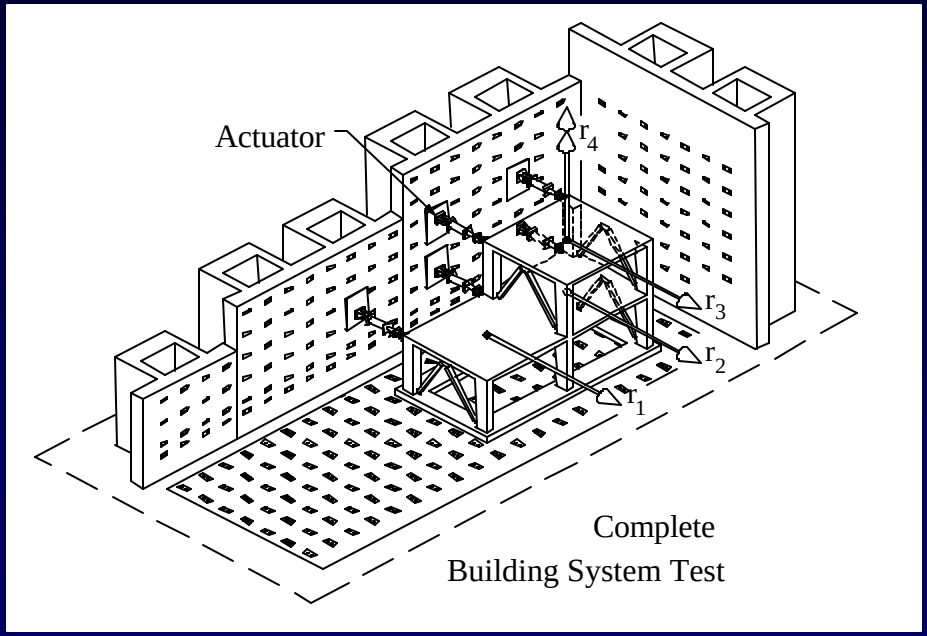


University of California, Berkeley
Shake Table (Source: Chopra, 2001)

- Real Time
- Limited Specimen Size

Earthquake Structural Performance Evaluation
Experimental Testing

Reaction Wall Testing
(Pseudo-Static or Pseudo Dynamic)

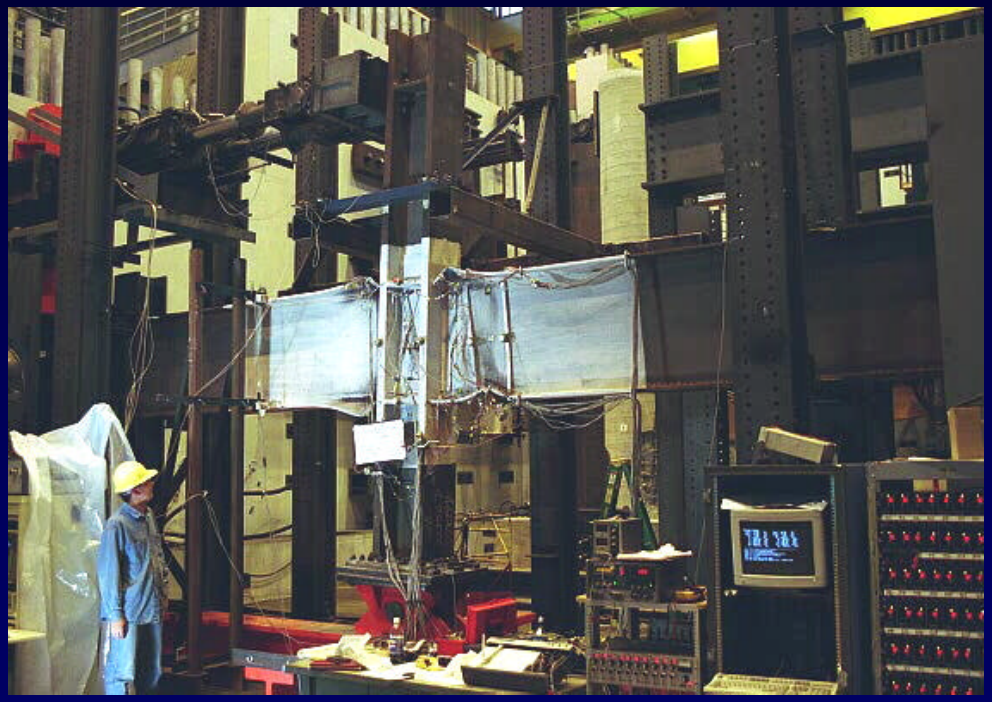


Lehigh University Multi-directional Reaction Wall Testing Facility

- Not Real Time
- Full-Scale Specimens

Earthquake Structural Performance Evaluation
Experimental Testing

Component Tests
(Pseudo-Static or Pseudo Dynamic)



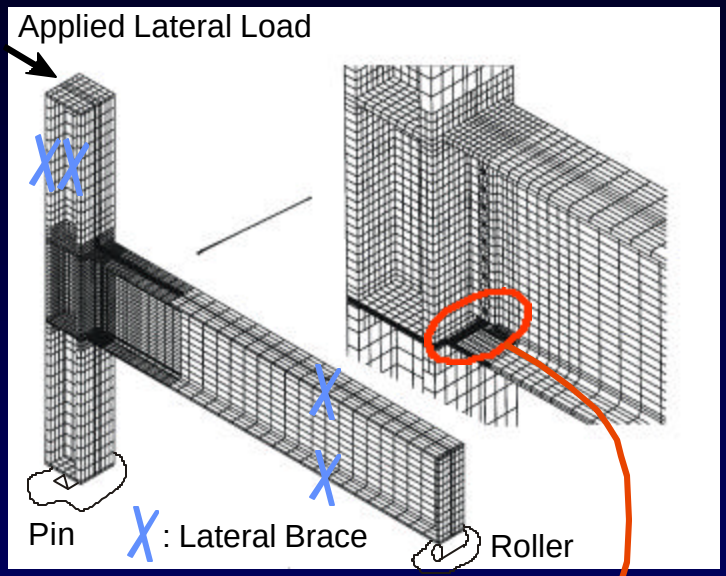
Lehigh University Multi-directional Reaction Wall Testing Facility

- Not Real Time
- Boundary Condition Effects
- Full-Scale Specimens

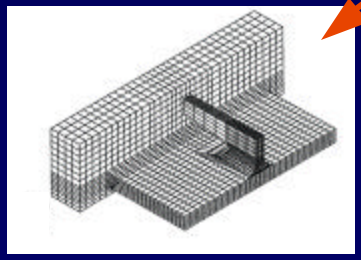
Earthquake Structural Performance Evaluation

Analysis

Finite Element Analysis of Welded Connection

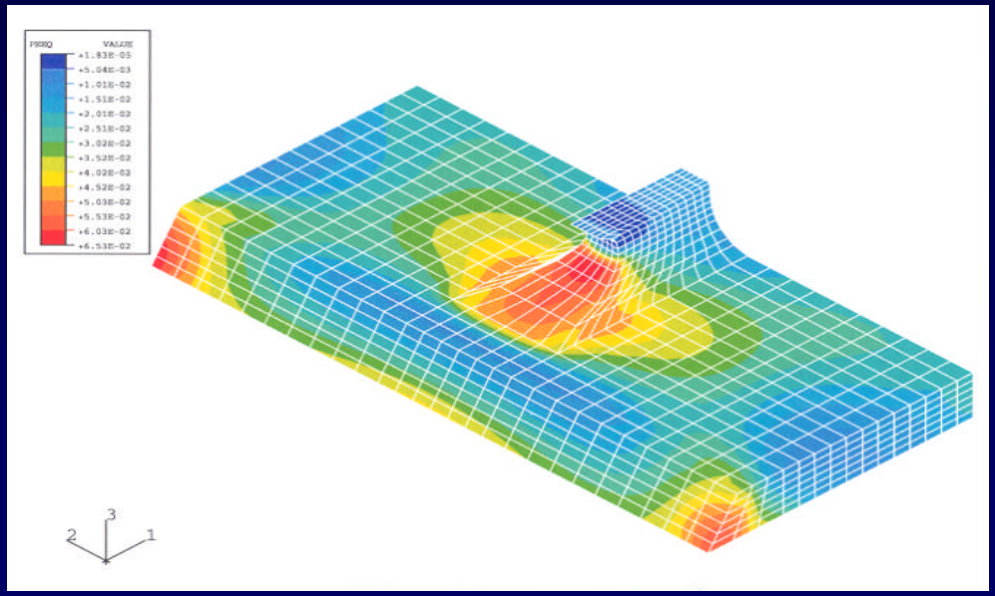


Global model



Sub-model

- Material and geometric non-linearities
- Emphasis on local joint region
- Cyclic load analysis

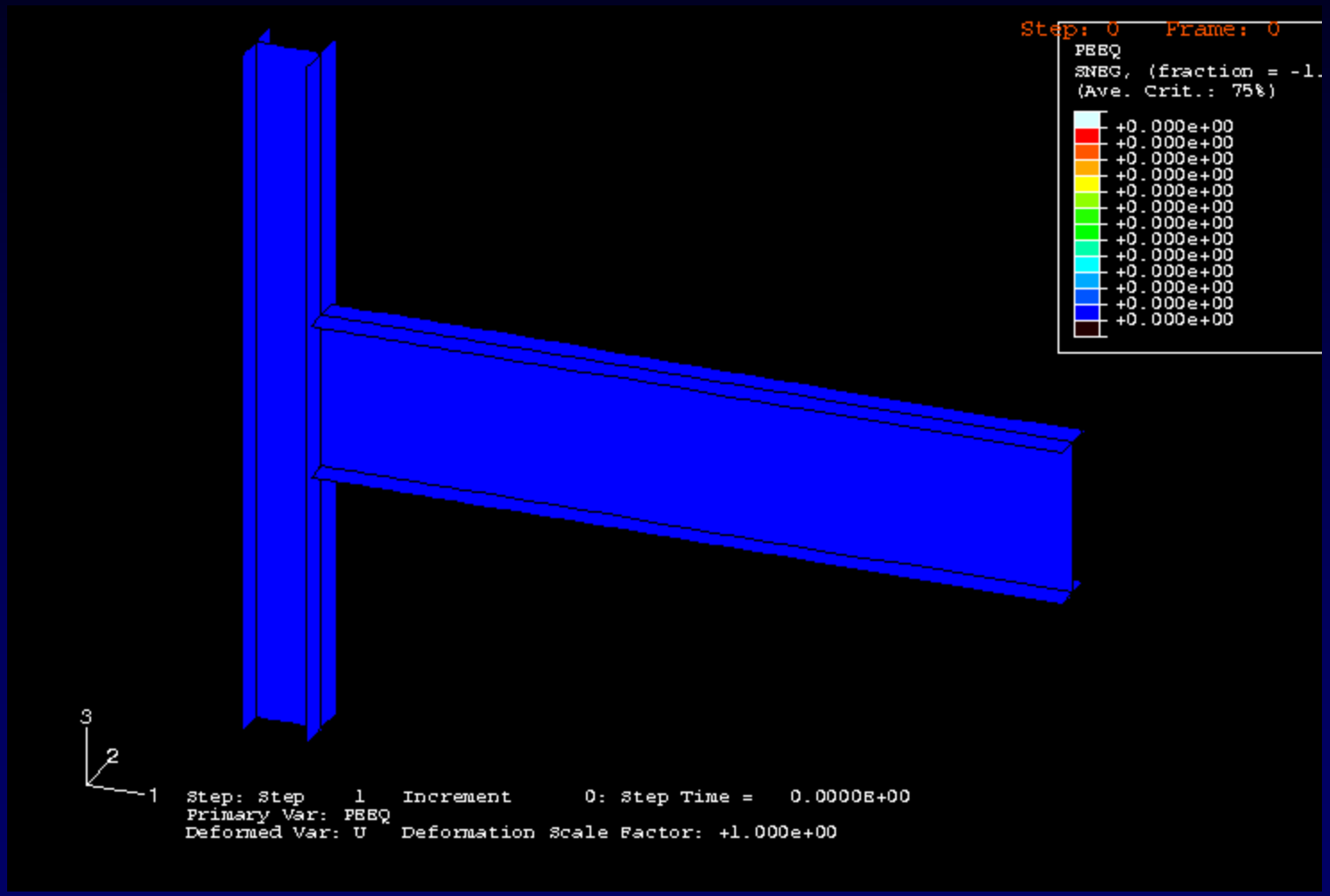


Equivalent Plastic Strain in Weld Access Hole Region

Earthquake Structural Performance Evaluation

Analysis

Finite Element Analysis of Welded Connection

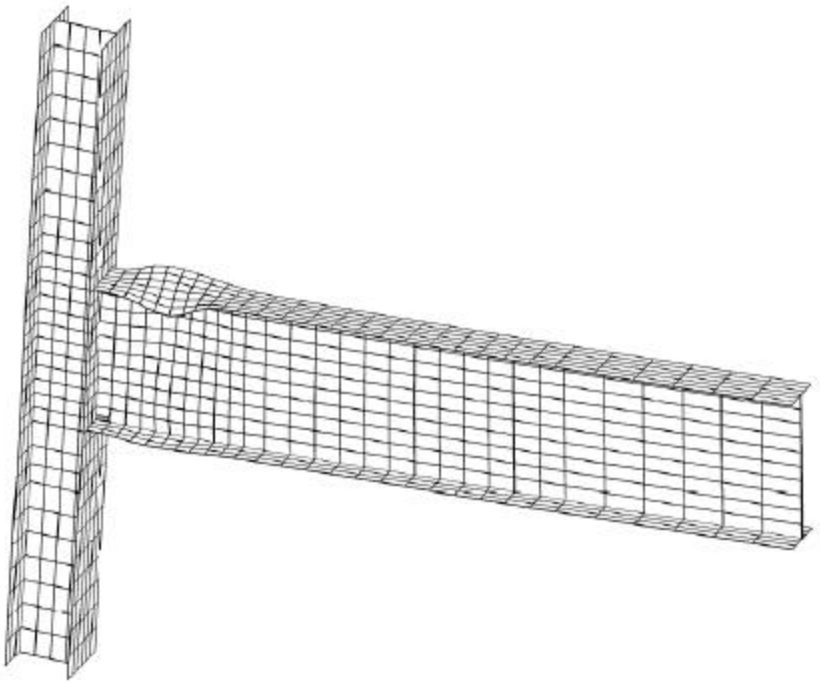


Cyclic Equivalent Plastic Strain

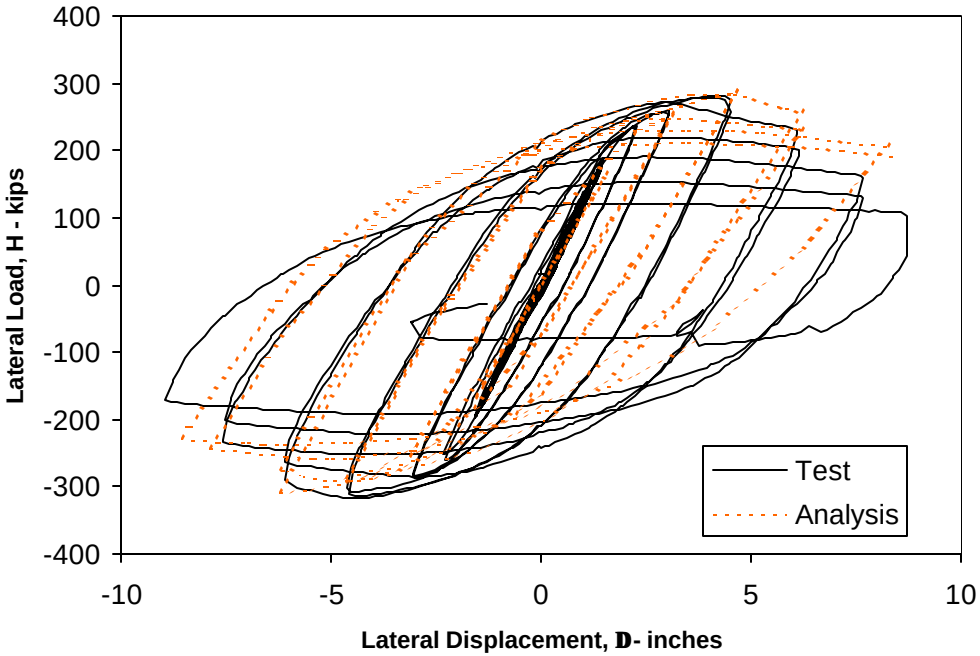
Earthquake Structural Performance Evaluation

Analysis

Finite Element Analysis of Welded Connection



Deformed Shape with Local Buckling

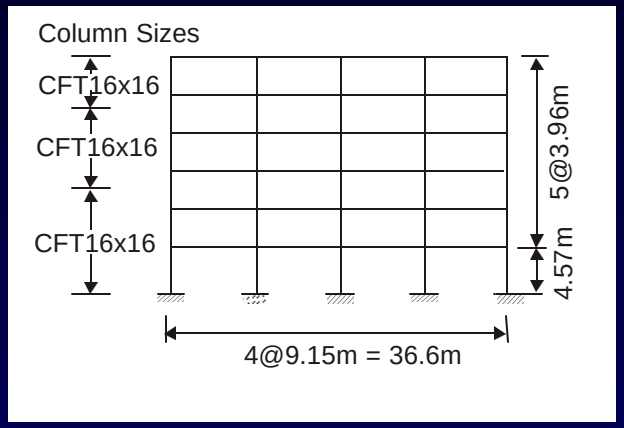


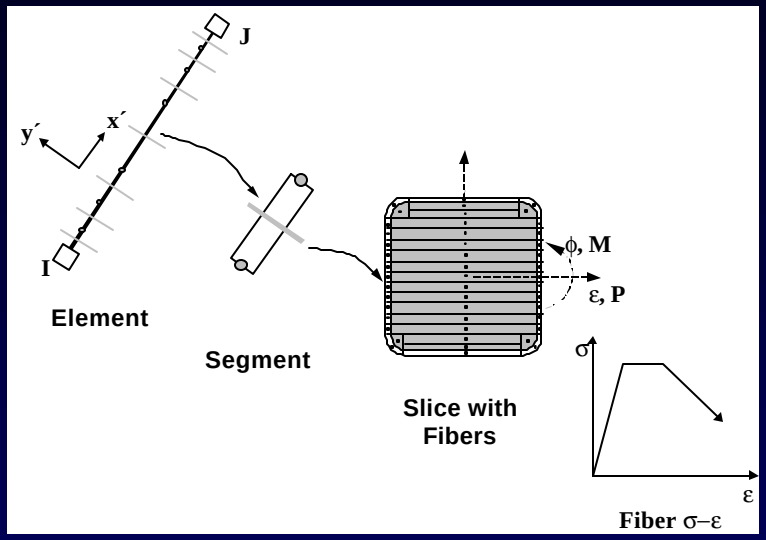
Lateral Load – Displacement Hysteretic Response

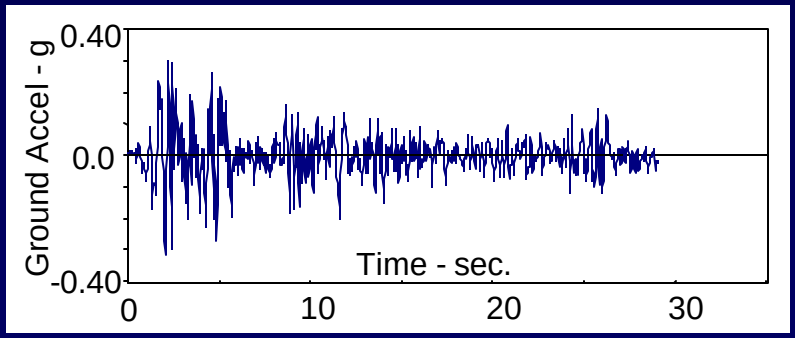
Earthquake Structural Performance Evaluation

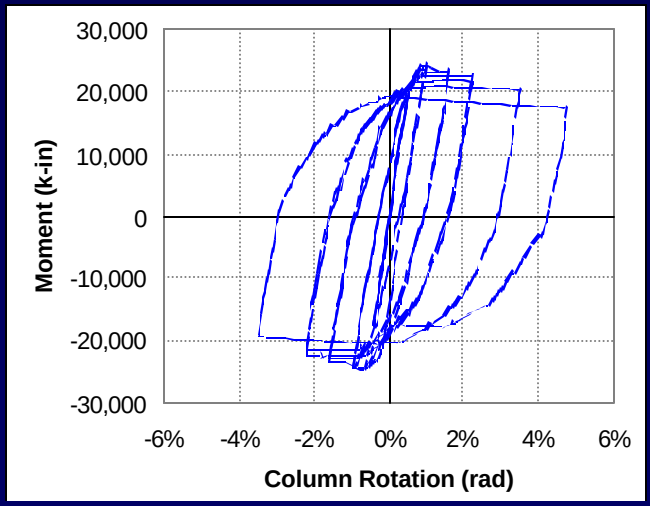
Analysis

Nonlinear Structural System Time History Analysis





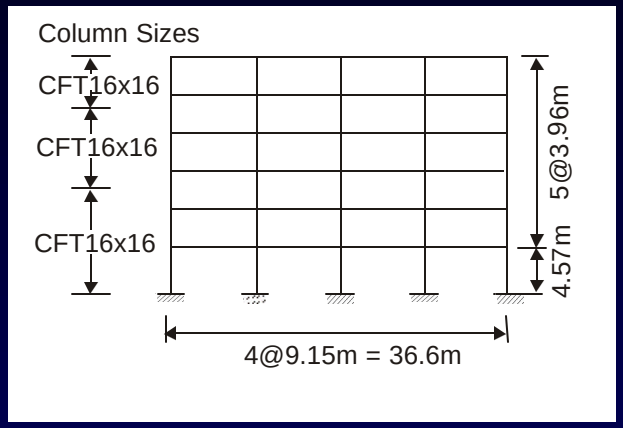


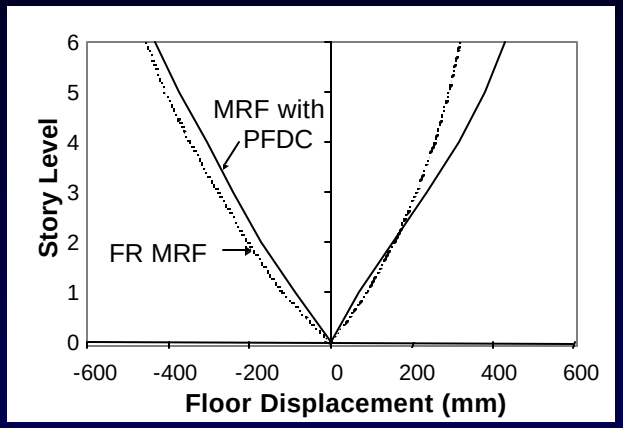


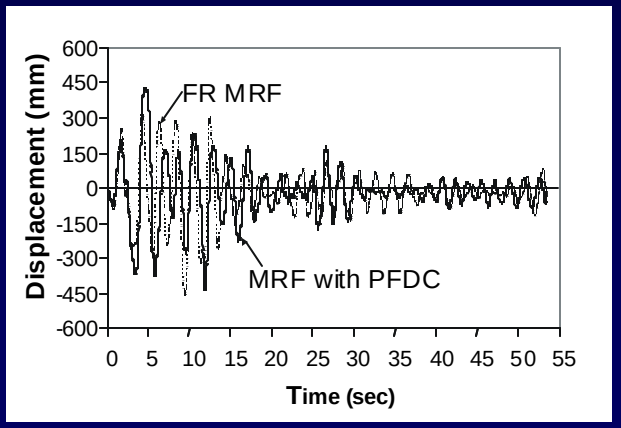
Earthquake Structural Performance Evaluation

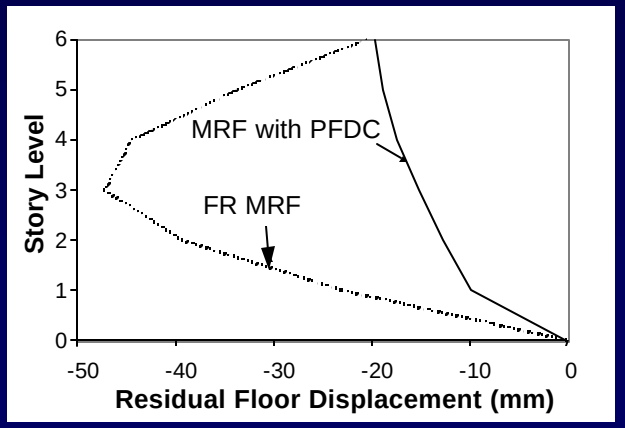
Analysis

Nonlinear Structural System Time History Analysis

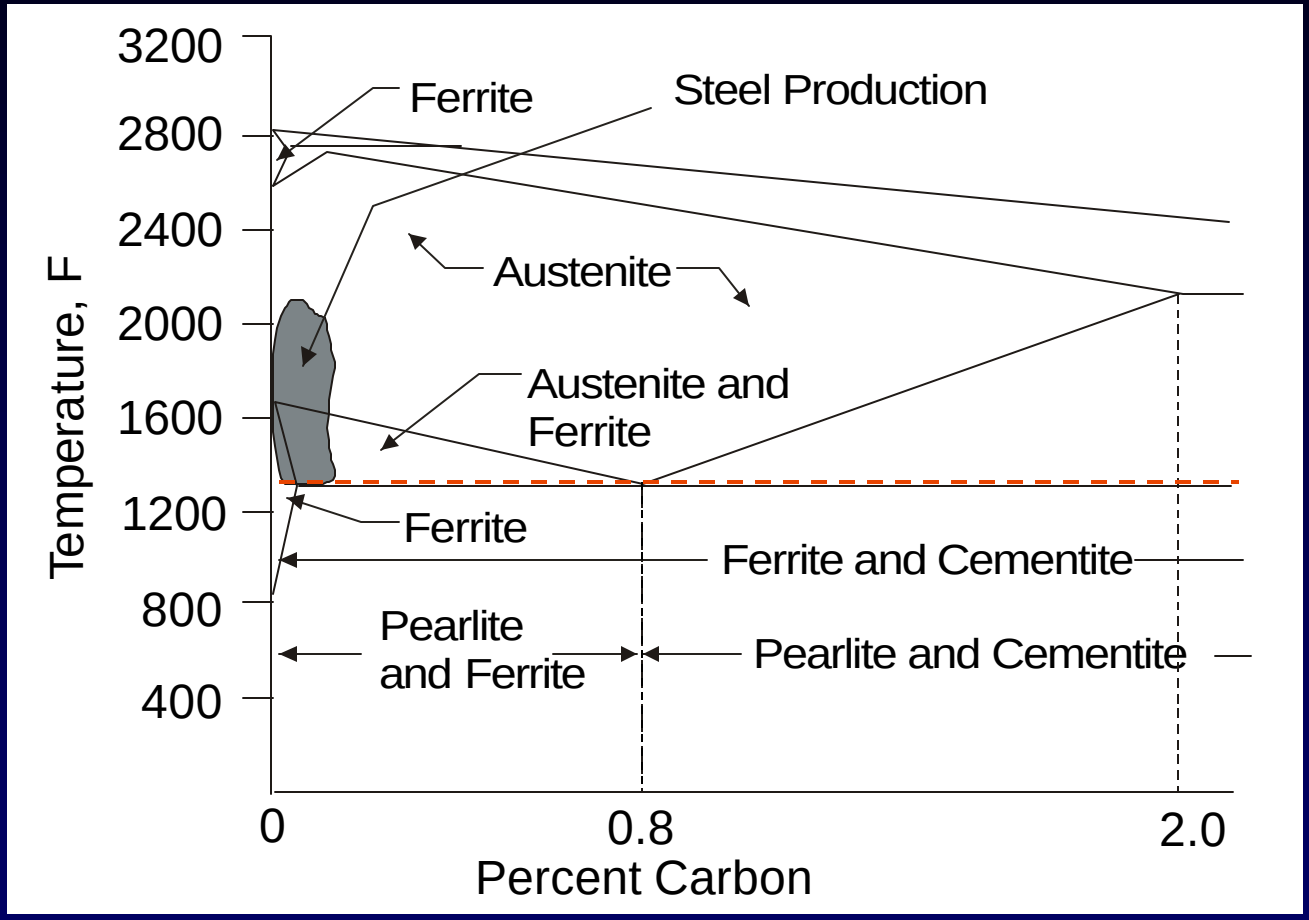








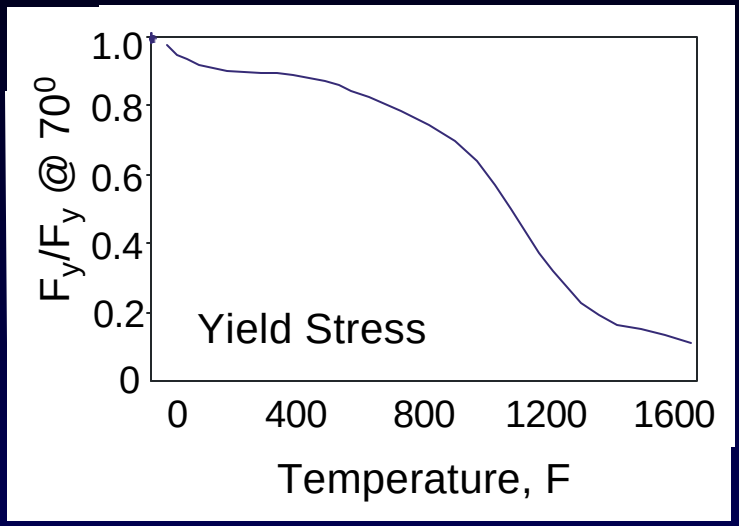
Structural Steel Behavior at Elevated Temperature
Steel Production

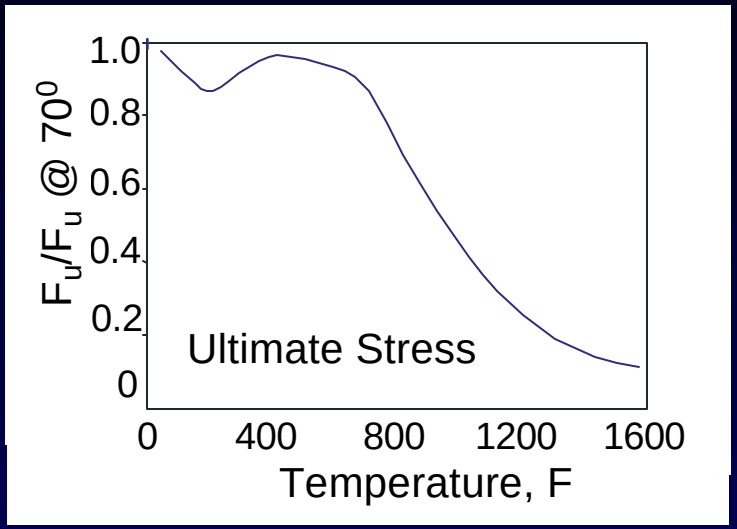


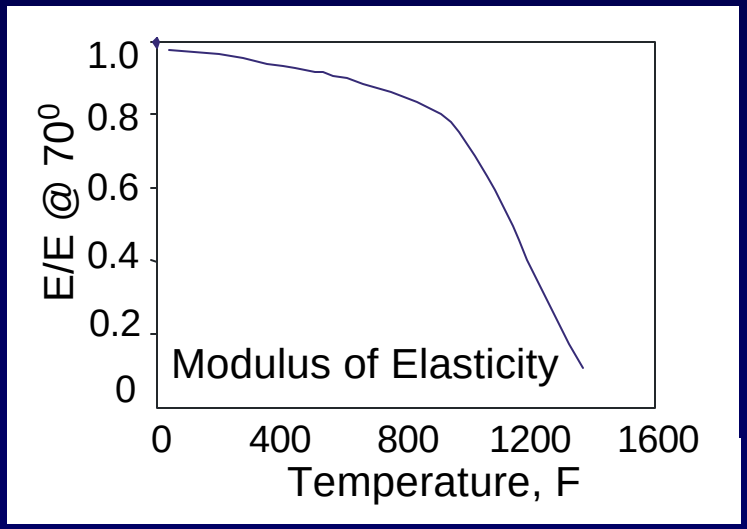
Phase Diagram for Structural Steel

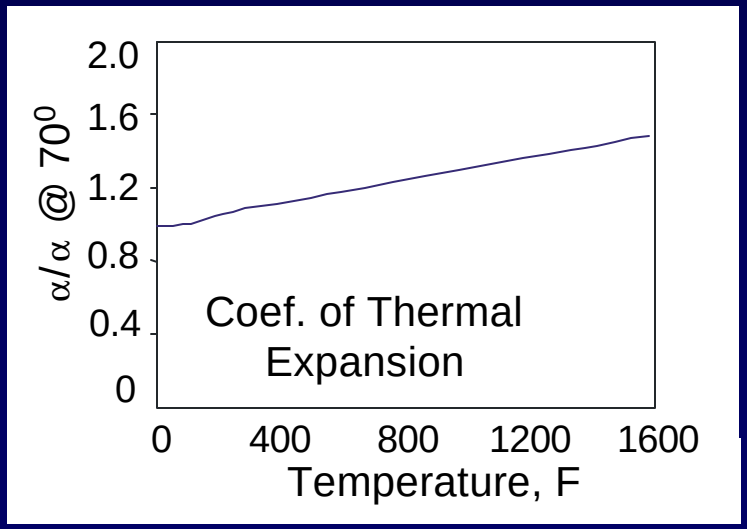
(Source: Tide, 2000)

Structural Steel Behavior at Elevated Temperature
Mechanical Properties



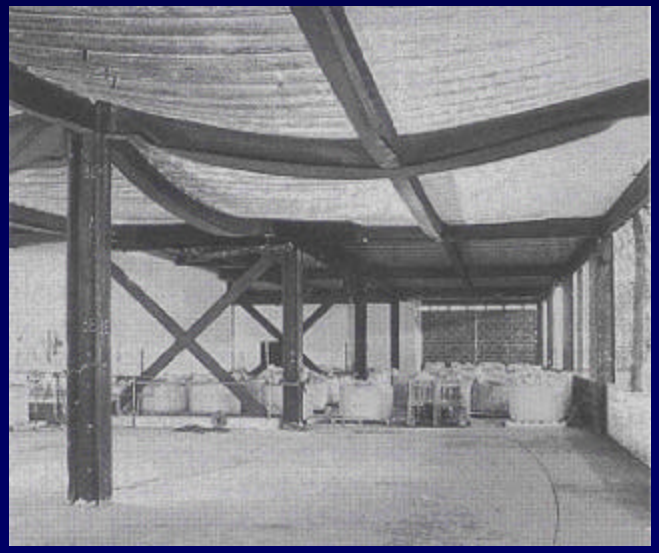






(Source: Tide, 2000

Structural Steel Behavior at Elevated Temperature
Structural Behavior



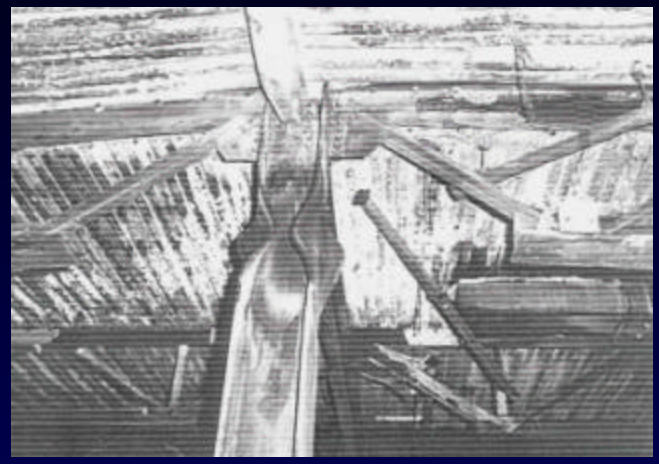
- Temperature Rise and Distribution
  - Change in Material Properties
  - Thermal Expansion
- Member Restraint
- Large Displacements
- Shifting Load

Cardington Lab Fire Test, U.K.
(Source: Gewain and Troup, 2001)

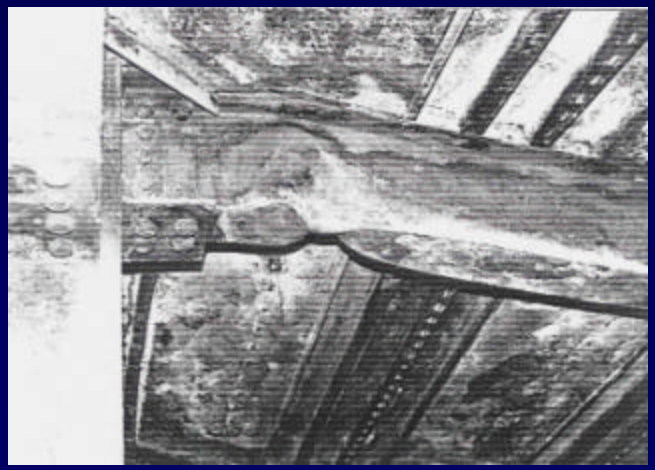
Structural Steel Behavior at Elevated Temperature

Structural Behavior

Beam Twisting



Column Local Buckling



Beam Local Buckling

Connection Failure

(Source: Tide, 2000)

Post-Fire Structural Integrity Evaluation

Dexter and Lu, 2001

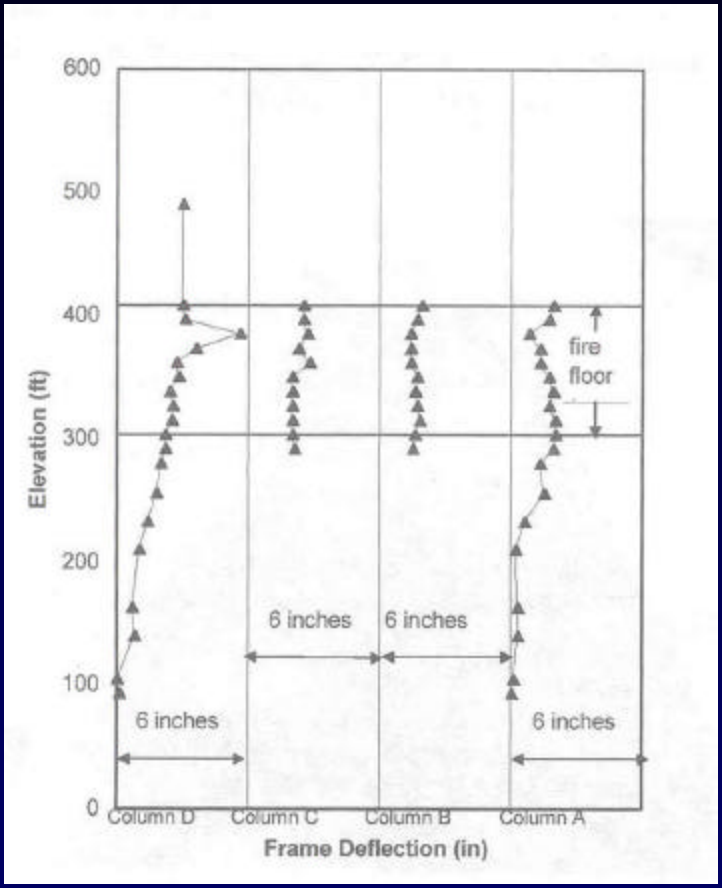
One Meridian Plaza (Phil, PA)

- 38-Story Steel Frame Bldg
- 1991 Fire, 18-hr Duration
- 9 Fire Floors

(Source: Dexter and Lu, 2001)

Post-Fire Structural Integrity Evaluation

Dexter and Lu, 2001



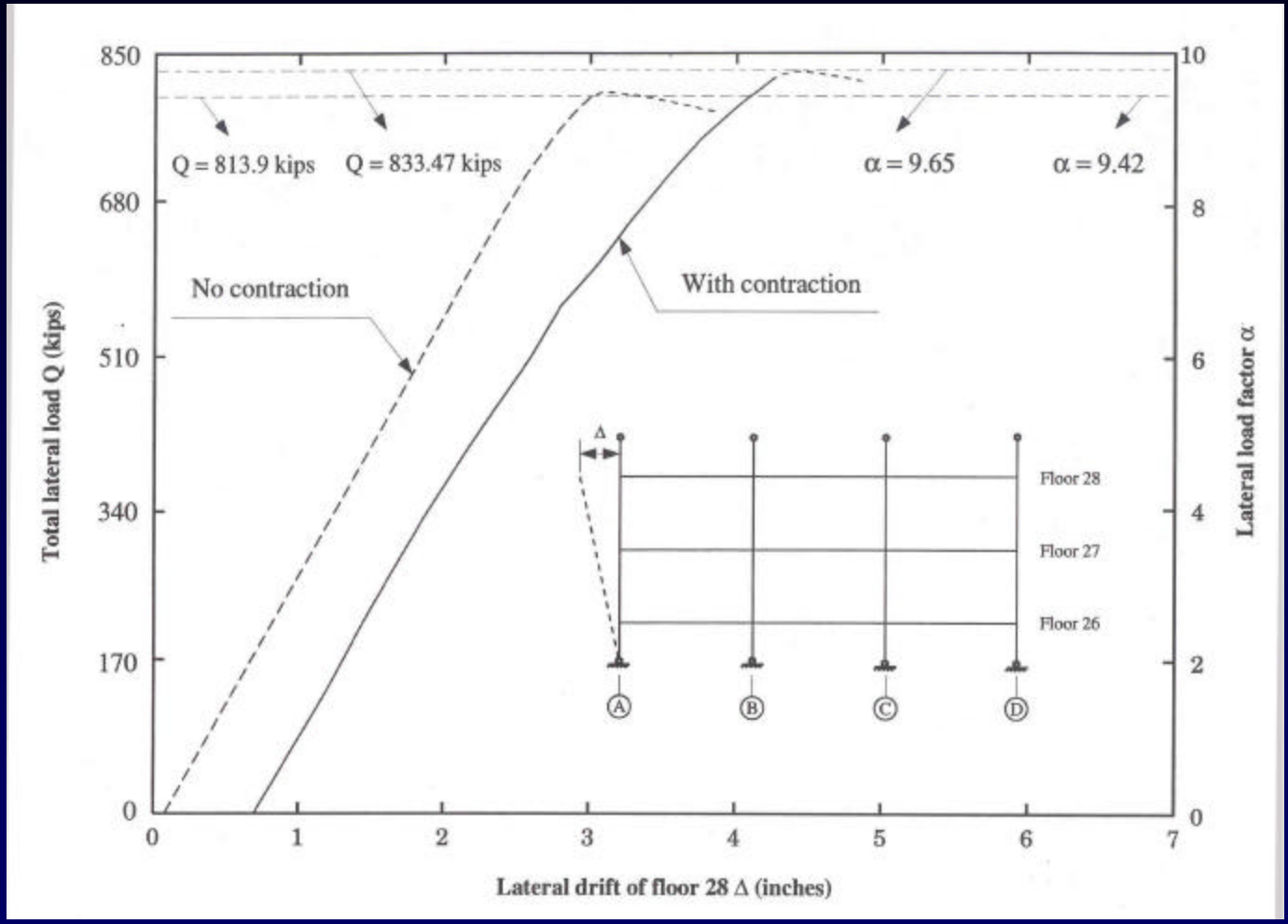
Building Position After Fire

- Inelastic Deformations During Fire
- Changes in Beam Length – *Locke*
  in Forces in Members

(Source: Dexter and Lu, 2001)

Post-Fire Structural Integrity Evaluation

Dexter and Lu, 2001



Non-linear Static Pushover Analysis

Research Issues and Needs

Testing -

- Structural component vs. structural system tests (effects of structural redundancy, restraint, connections, non-load bearing elements)
- Thermal input
- Measuring structural response (thermal effect on sensors)
- Test protocol
- Adequate facility for conducting fire testing

Analysis -

- Calibration of models with test data
- Structural component vs. structural system modeling (effects of structural redundancy, restraint, connections, non-load bearing elements)
- Thermal input
- Time scale
- Non-linearities:
  - Change in material properties due to thermal input and loading
  - Geometric non-linearities (large displacements; local buckling; load shifting)
  - Connection modeling (stiffness and strength deterioration; fracture)

Summary and Conclusions

(1) Success has been achieved in predicting the performance of structures to extreme earthquakes

- Sophisticated analytical models
- Experimental testing

(2) Predicting the fire resistance and performance of a structure has several challenges. The complexities involved require sophisticated analytical models, and experimental testing to calibrate these models.